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*Published in:*
ANTEC 2013 Conference Proceedings

*Publication date:*
2013

*Document Version*
Publisher's PDF, also known as Version of record

# INITIAL VERIFICATION OF AN INDUCTION HEATING SET-UP FOR INJECTION MOLDING

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## Abstract

Molding of thin and long parts by injection molding leads to special requirements for the mold in order to ensure proper filling and acceptable cycle time. This paper investigates the applicability of embedded induction heating for the improvement of the filling of thin long parts. The object selected for the investigation is a thin spiral.

For the complete molding of the component, elevated mold temperatures are required. For this propose a new injection molding set-up was developed, which allows rapid heating of the cavity wall by an induction heating system. The temperature was measured by two thermocouples placed in the die insert. The system was used to heat up the cavity wall with heating rates of up to 10 °C/s. Experiments were carried out with ABS material. The lengths of the object were measured by a suitable measurement set up.

The experimental result show that the use of the induction heating system process is an efficient way for improving the filling of the cavity.

## Introduction

For the mass fabrication of long and thin polymer components, injection molding represents one of the most important manufacturing processes because it matches the capabilities of a low-cost process and the requirements of such products, in terms of dimensions and tight tolerances.

A crucial step during the process is the filling of the cavity. It is important to understand the influence of the process parameters on the filling of a cavity for the optimization of the process and to obtain completely filled parts complying with the specifications. [1]
Some defects in molded parts are: weldlines, sink marks, void, low quality grain, high roughness [2], [3]

The situation becomes more critical for smaller parts (with same ratio between length and width of the cavity features) due the faster freezing of the melt through the cross section.

Several studies suggested that mold temperature is the predominant factor affecting cavity filling and that high-mold temperature promotes feature transfer during molding. [4], [1].

This paper deals with the injection molding of a long and thin spiral object. The goal of the paper is to verify the improvements in the replication of a macro object with the auxiliary use of an induction system for fast warm up of a die insert. A 2 factors and 2 level full factorial DOE is carried out. The two controlled variables are the injection speed and the insert temperature. After the injection molding experiments the length and the weight of the spiral object are measured with a proper measurement set up.

The paper presents the initial experimental validation of the first generation induction heating system.

## Basic theory of induction heating

From theoretical basis of electromagnetism, the Maxwell’s equations are used to describe the electromagnetic behavior of an induction field [5]:

$$\nabla \cdot D = 0$$

$$\nabla \times \mathrm{H} = J + \frac{\partial D}{\partial t}$$

$$\nabla \cdot B = 0$$

$$\nabla \times \mathrm{E} = -\frac{\partial B}{\partial t}$$

where D is the electric induction:

$$D = \varepsilon E$$

$\varepsilon$ is the permittivity of the material, H is the magnetic field intensity:

$$\mathrm{H} = B/\mu$$

$\mu$ is the permeability of the material, E is the electric field intensity, J is the current density, and B is the magnetic flux density. When a variable electromagnetic field exists, eddy current is induced on the surface of work piece to be heated. Due to the well-known skin effect, medium frequency currents are concentrated in a shallow surface layer because of the rapid attenuation of high frequency fields as they penetrate the conductor. The current density J in the conductor decreases exponentially with depth from the surface, as given by:

$$J = J_S e^{-d/\delta}$$

where $J_S$ is the current density at surface, d is the depth and $\delta$ is a skin depth parameter calculated by:

$$\delta = \sqrt{\frac{\rho}{\pi f \mu_R \mu_0}}$$

where $\rho$ is resistivity of the material, f is frequency, $\mu_R$ is relative permeability and $\mu_0$ is the permeability constant, ($4\pi \times 10^{-7}$ H/m). It can be seen that higher frequency results in less skin depth. A certain amount of Joule heat is generated when an electrically conductive material is placed in an alternating electromagnetic field, depending on the magnetic properties and resistivity of the material. The Joule heat Q can be obtained by:

$$Q = \frac{1}{2}\rho |J|^2$$

This last equation show that the heating dissipated from the eddy current can be used for the warming up the mold surface. In the induction heating set-up the transfer heat depend mainly from 2 process parameters: the switch on time of the system and the input voltage. These 2 parameters were used to control the final desired mold temperature.

## Induction assisted variothermal set-up.

In this work an induction heating was used as a means to heat a mold insert. Experiments were carried out at a fixed current frequency of approximately 10 KHz.

In Figure 1 a schematic representation of the circuit is show, where R2 and L4 are respectively the resistance and the self-induction of the metal insert.

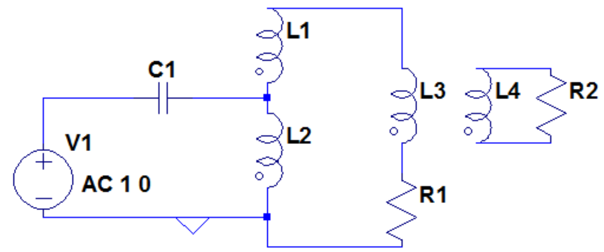


**Figure 1: Schematic representation of the electric circuit for the induction heating system**

The coil system to create the magnetic field is mounted just behind a plate insert of a thickness of 4 mm. The coil system is constituted of 4 different parts: a hollow metallic cylinder for holding the coil, a ferrite core to concentrate the magnetic field in an isolated area, the copper coil for the generation of the magnetic field and finally a high temperature epoxy composite for establishing a fixed connection between the previous three components. The copper coil consists of a tube that allows the circulation of cooling water. The copper tube is covered by a polymeric sheath for ensuring electric insulation. The electrical and cooling connections are placed on the side of the mold.

The mold assembly has one cavity for the insertion of the induction system coil. A thin mold insert is placed on top of the coil assembly. The insert is interchangeable so that different geometries can be tested. The counter part of the insert is equipped with 2 thermocouple sensors and the ejection system. The 2 thermocouple sensors are used to measure the insert temperature. They are designed with a spring device for keeping contact with the surface.

The system to generate the magnetic field is essentially a power supply to increase the frequency of the AC from 50 Hz to 10 KHz, a transformer and a capacitor. An additional load match transformer (L1 and L2) is used to change the effective number of winding in the main coil (R1, L3).

## Process description

At the beginning of the variothermal injection molding process, the injection molding machine closes the mold. When the mold is closed it sends a signal to the external induction system to start the heating period. When the heating period is concluded the injection machine starts the injection of the material. The next step is the cooling phase, with a constant circulation of oil inside the mold at 30° C. When the temperature of the part is low enough for demolding, the machine opens the mold and ejects the part. Everything is made in an automatic way for ensuring stable conditions.

## Insert generation

The selected feature for this experiment was a spiral, as shown in Figure 2. It was chosen to have a clear and immediate overview of the filling behaviour of the polymer inside the die with just a quick visual comparison between the samples.

**Figure 2: CAD model of the spiral mold insert**

The cross section of the spiral channel has a width of 2 mm on the top surface and a width of 0.97 mm at the base. The depth is 0.5 mm. The variable cross section was decided for a better extraction of the polymer part.
A milling process was used to generate the spiral insert shown in Figure 2. The outside dimensions of the insert are 85mm x 85mm and the material is a tool steel with the following composition: 1.0% C, 1.0% Mn, 5.0% Cr, 0.3% Ni, 1.0% Mo, 0.15–0.50% V.

## Molding experiments

The induction heating variothermal injection molding system was tested using the previously described insert structure. The material used in the experiment was ABS (Acrylonitrile Butadiene Styrene) with the properties reported in Table 1

| PROPERTY | VALUE |
|---|---|
| Commercial Name | Rotec r ABS 1001 |
| Producer | ROMIRA GmbH |
| Density | 1.06 g/cm^3 |
| Drying Temperature | < 80 ° C |
| Drying Time | 2 to 4 hr |
| Melt temperature | <260 ° C |

**Table 1. Material Properties as indicate in the material data sheet [6]**

The molding experiments were carried out on an Arburg Allrounder 370A 600-70 all drive injection machine.
To evaluate the filling behaviour a 2 factors 2 levels full factorial DOE was carried out. The two controlled variables are the injection speed and the insert temperature. Constant settings were used for the heating and cooling of the mold. In the following tables the main process parameters are reported:

| PARAMETER | UNIT | VALUE |
|---|---|---|
| Polymer Injection temperatures | °C | 240 |
| Injection Pressure | bar | 2000 |
| Cooling time | s | 20 |
| Mold base temperature | °C | 35 |

**Table 2: Constant molding parameters**

| PARAMETER | UNIT | EXP 1 | EXP 2 | EXP 3 | EXP 4 |
|---|---|---|---|---|---|
| Injection Velocity | mm/s | 100 | 100 | 150 | 150 |
| Max Mold Temperature | ° C | 35 | 140 | 35 | 140 |
| Heating time | s | 0 | 20 | 0 | 20 |
| Induction Heating Voltage | Volt | 0 | 160 | 0 | 160 |

**Table 3: Variable injection molding parameters**

## Results

An example of the molded spiral is reported in Figure 3

**Figure 3: Example of the spiral molding**

Molding performance was evaluated by recording the length and the weight of the spiral for the different process setting.

For the length of the spiral a proper set-up was established. It consists in a polymeric copy of the metallic insert with the addition of thin marks with 1 mm interval on the inner curve of the spiral (Figure 4). All the measured samples were picked up randomly from the testing batch after the stabilization of the process.

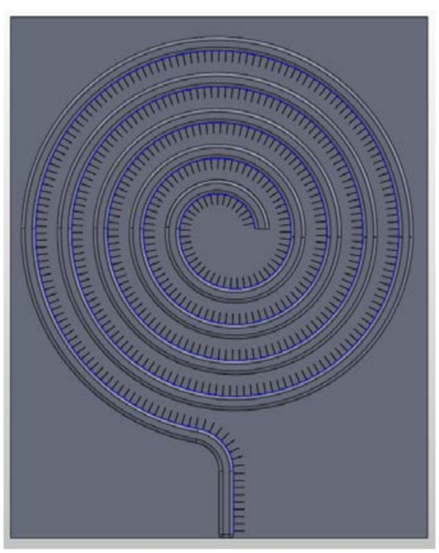

**Figure 4: Measurement device**

In the next two tables the experimental result are shown:

| INJECTION SPEED 100 mm/s | | | | |
|---|---|---|---|---|
| | **EXP 1** | | **EXP 2** | |
| T[$C^0$] | 35 | | 140 | |
| | Length [mm] | Weight [g] | Length [mm] | Weight [g] |
| 1 | 91 | 0.0875 | 98 | 0.0969 |
| 2 | 91 | 0.0875 | 98 | 0.0972 |
| 3 | 91 | 0.0878 | 98 | 0.0974 |
| **Average** | **91** | **0.0876** | **98** | **0.0971** |
| STD | 0 | 0.0002 | 0 | 0.0003 |

**Table 4: Result with injection speed of 100 mm/s**

| INJECTION SPEED 150 mm/s | | | | |
|---|---|---|---|---|
| | **EXP 3** | | **EXP 4** | |
| T[$C^0$] | 35 | | 140 | |
| | Length [mm] | Weight [g] | Length [mm] | Weight [g] |
| 1 | 97 | 0.0927 | 104 | 0.1033 |
| 2 | 96 | 0.0925 | 105 | 0.1033 |
| 3 | 97 | 0.0928 | 105 | 0.1033 |
| **Average** | **96.67** | **0.0926** | **104.67** | **0.1033** |
| STD | 0.58 | 0.0002 | 0.58 | 0 |

**Table 5: Result with injection speed of 150 mm/s**

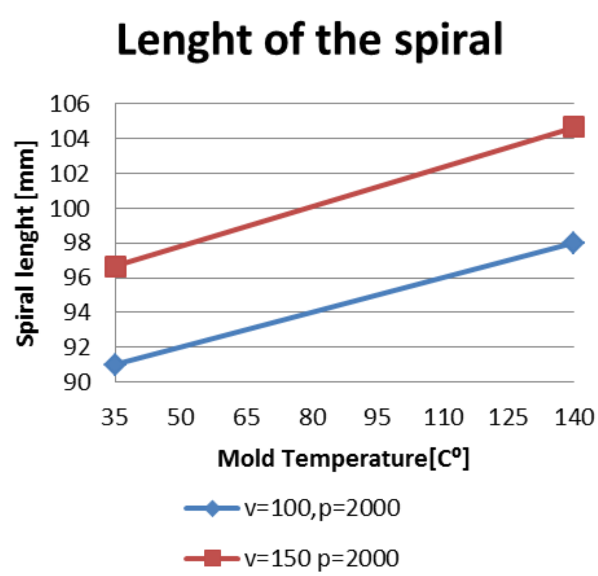


**Figure 5: Experimental analysis result of the length with cold and hot insert**

As can been seen in the above diagram in Figure 5 and in the tables, it is shown that the utilization of the induction heating system can provide a better replication of the geometry. In the first 2 experiments with an injection speed of 100 mm/s the spiral dimension length increases of 7 mm when the temperature is increased from 35 $C^0$ to 140 $C^0$; this increment is approximately 8% of the total length. In the third and forth experiment with an injection speed of 150 mm/s the spiral dimension length increases of 8 mm with the temperature change from 35 $C^0$ to 140 $C^0$; this increment is approximately 8% of the total length.

Looking at the example part in Figure 3 it could be seen that the molten polymer did not fill the entire cavity of the insert and only a very limited portion of the structure was created. This is due to the fact that in these tests a temperature of the mold lower than the Tm of the ABS material was used and a premature freezing problem appears along the flow path. This phenomenon made the replication more difficult in the areas far away from the gate. It is also observed that a temperature gradient is established across the mold surface due to a low temperature in the outside part of the spiral compared to the central part. This observation is supported by the geometry of the induction system that creates a focused heated zone not covering the entire insert surface. For these reasons, the dimension and geometry optimization of the induction coil will be the starting point for further investigation.

## Conclusion

In this study, a new experimental induction heating system combined with oil cooling is utilized to achieve a rapid mold surface temperature variation to assist injection molding of a testing spiral part. The results showed a substantial improvement of the filling behaviour of the polymer inside the cavity with the use of the new induction system implemented in the injection molding machine.

In this project, the filling behaviour of the polymer inside a spiral insert was investigated. Future work will concentrate on the molding of the same feature with different mold materials with magnetic and non-magnetic properties for testing the thermal behaviour.

## Acknowledgment

The present research was carried out within the Innomold project (Innovative Plastic Products and More Energy Efficient Injection Molding Processes) supported by the Danish Council for Technology and Innovation.

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Key Words: Injection molding, Induction Heating, Surface Heating, Long and Thin geometry.